Non-R&D innovation of manufacturing firms: theory and evidence from the third European Community Innovation Survey

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Abstract:

Non-R&D innovation is a prevalent economic phenomenon, though R&D has been the central focus of policy making and scholarly research in the field of innovation. The third European Community Innovation Survey (CIS-3) shows that more than half of the European innovative firms did not conduct intramural or extramural R&D. Instead of investing in R&D, they acquired advanced machinery, purchased patents and licenses or carried out training and marketing activities to develop product or process innovations. In this paper we develop a two-stage non-cooperative game to model the decisions of firms with regard to the size of their innovation expenditures or budget and the allocation of this budget between R&D and non-R&D innovation activities. We demonstrate how the initial productivity of firms, the share of their expenditures in non-R&D innovation activities, and the potential cost reduction achieved by the application of existing technologies or the development of new technologies would affect the decisions of firms. Following a theoretical framework and arguments, we examine the CIS-3 data to provide empirical evidence.

Key Words: Non-R&D innovation, Community innovation survey, CIS

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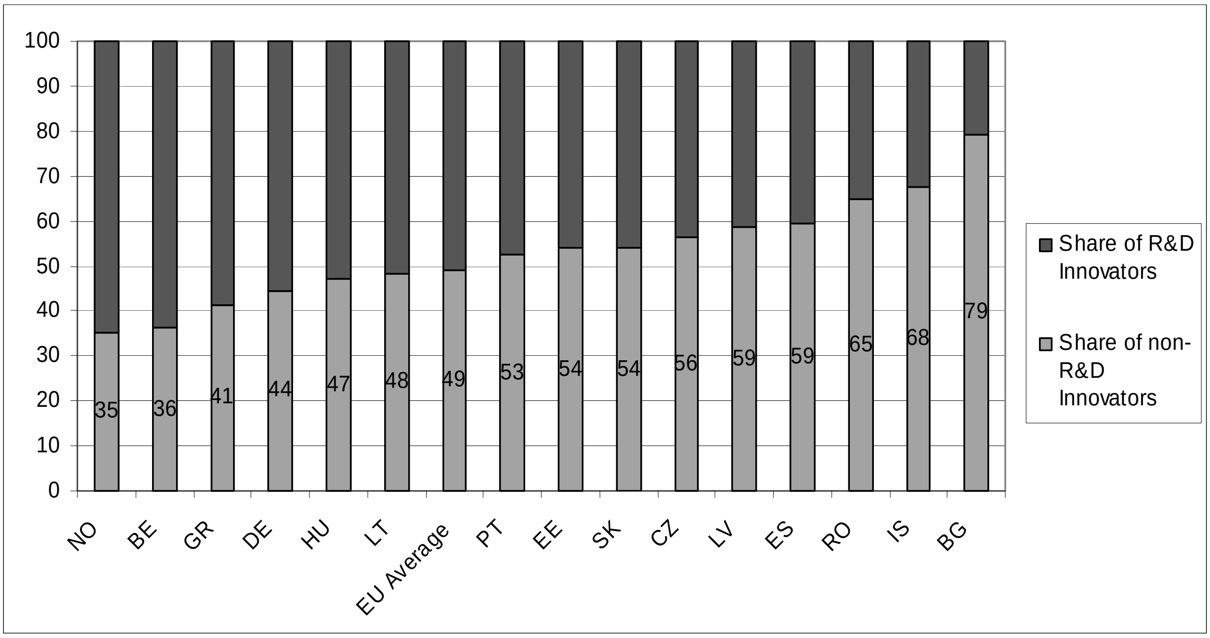
1. Introduction

Until very recently Research & Development (R&D) has been synonymous with technology and innovation in many publications on science, technology and innovation. A rough estimate by the authors, based on Trend Chart data, reveals that a minimum of 95 percent of all funding for innovation in the European Union is to support R&D. The Lisbon strategy, which aimed to build Europe by 2010 the most competitive and dynamic knowledge-based economy in the world, incorporated as a goal that R&D expenditures in the European economies should reach, on average, 3 percent of Gross Domestic Product (GDP) by 2010. As emphasized in the Lisbon strategy, R&D intensity is extensively used by scholars and policy makers as a benchmark for measuring the innovativeness of a firm, a region and a country.

The importance of R&D is the very reason explaining the predominant role of R&D in innovation studies and policy making. R&D is the source of many productivity enhancing innovations. It is essential to competitiveness of fast-growing/high technology industries such as pharmaceuticals, automobiles, ICT and machinery. R&D is also critical to the absorptive capacity of a firm and an industry (Cohen and Levinthal, 1989) and is associated with countries' advantages in their terms of trade. In addition, R&D activities create demand and supply for high caliber human resources which in turn give impetus to the development of the educational system in a country.

Although R&D is vital for the innovation activities of firms and the competitiveness of an industry and a country, the third European Community Innovation Survey (CIS-3) shows that about half of the European firms which report to have product or process innovations do not conduct intramural or extramural R&D (Figure 1). In the technologically less developed Eastern European countries, the shares of non-R&D innovators are higher than in the technologically more developed Western European countries. Breaking down the data of non-R&D innovators by sector, we find that non-R&D innovators are concentrated in low technology manufacturing and in services sectors (Figure 2). The distribution of these non-R&D innovators is skewed towards small and medium sized firms (Figure 3). Given that a significant number of firms innovate without conducting R&D, non-R&D innovation activities should have drawn considerable attention from academics and policy makers. The Oslo Manual provides a broad definition of innovation in recognition to the fact that diffusion is crucial to realizing the economic benefits of innovation and that R&D only covers part of all of the different methods that firms use to innovate. However, there is a lack of systematic studies on the means, other than R&D, that firms use to innovate as well as thorough research that links different types of innovation to the economic performance of firms.

Figure 1: R&D and Non-R&D Innovators: Breakdown by Country (CIS-3, Micro-aggregated data)

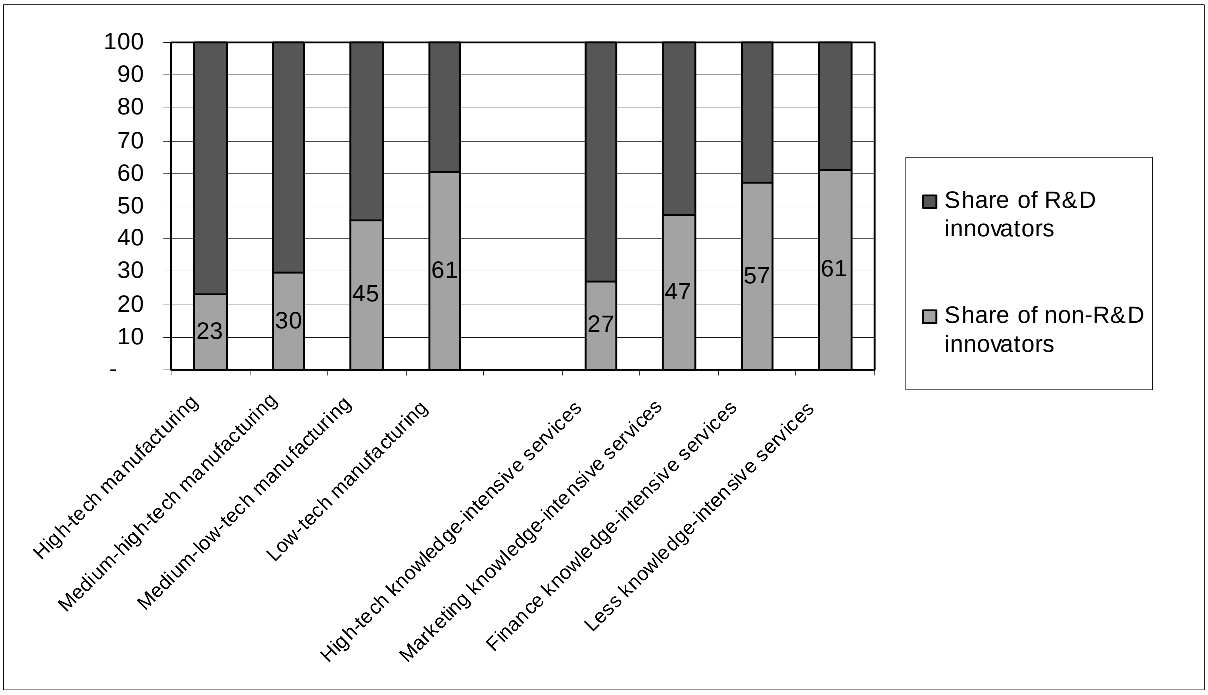


Source: Authors' calculation.

Notes: 1. Non-R&D innovators are defined as innovative firms which have product or process innovations, but do not perform intramural and extramural R&D. R&D innovators are defined as innovative firms that perform intramural and/or extramural R&D.

2. NO, BE, GR, DE, HU, LT, PT, EE, SK, CZ, LV, ES, RO, IS and BG represent Norway, Belgium, Greece, Germany, Hungary, Lithuania, Portugal, Estonia, Slovakia, Czech Republic, Latvia, Spain, Romania, Iceland and Bulgaria, respectively.

Figure 2: R&D and Non-R&D Innovators: Breakdown by Sector (CIS-3, Micro-aggregated data)

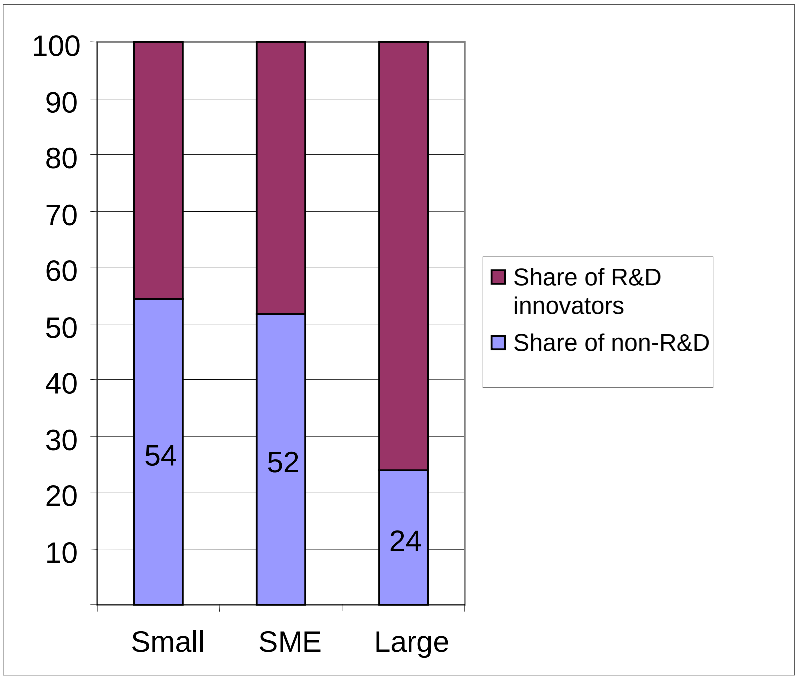


Source: Authors' calculation.

Notes: 1. The definition of Non-R&D innovators and R&D innovators is the same as in Figure 1.

2. The definition of the sectors is fully in line with the standard of Eurostat which is available at http://europa.eu.int/estatref/info/sdds/en/htec/htec_base.htm.

Figure 3: R&D and Non-R&D Innovators: Breakdown by Firm Size (CIS-3, Micro-aggregated data)



Source: Authors' calculation.
Note: 1. The definition of Non-R&D innovators and R&D innovators is the same as in Figure 1.
2. Small firms are those firms employing 10-49 employees. Medium firms are those ones employing 50-249 employees. Large firms employ 250 or more employees.

In this paper, we aim to fill this gap by developing a two-stage non-cooperative game to model the decisions of firms with regard to the size of their innovation expenditures or innovation budget and the allocation of their budgets between R&D and non-R&D innovation activities. We demonstrate how the initial productivity of a firm, the share of its budget in non-R&D innovation, the potential cost reduction achieved by buying existing technologies or investing in R&D and the strategic interaction between the firm and its competitors affect these decisions. By examining the data of the third European Community Innovation Survey (CIS-3), we provide empirical evidence to support the theoretical arguments.

The remainder of this paper is organized as follows: Section 2 reviews the relevant theoretical contributions to the understanding of R&D activities of firms. Section 3 establishes a theoretical framework to analyze factors influencing the decisions of a firm regarding the size and the allocation of its innovation expenditures. Section 4 presents empirical evidence drawn from the CIS-3 data to support the theoretical propositions and discusses policy implications. Section 5 concludes.

2. Review of Theoretical Literature

The models studying R&D activities of firms can be classified into two categories, i.e. tournament and non-tournament models (Beath et al., 1995). In tournament models, firms engage in competition for technological breakthroughs or patent applications. The single winner of the competition will take all benefits. In tournament models of a patent race, a firm's probability of making a discovery and obtaining a patent at a certain point in time, i.e. winning the tournament, depends on the firm's current R&D expenses and accumulated experience in R&D activities.[1] In non-tournament models, firms apply for patents to protect the outcomes of their R&D investments, but they can not prevent other firms from achieving the same outcomes by investing in R&D. No matter whether models incorporate tournament or non-tournament elements, they reflect the two basic motives for firms' R&D investments, which are increasing profits in the future by allocating resources to R&D and obtaining a strategic advantage over rivals (Beath et al., 1995).

In an article related to the determinants of the number of firms that engage in R&D and the expected welfare performance of the industry, Quirmbach (1993) argued that a firm must consider the cost of doing research, the probability of succeeding, and the likely degree of competition in the market when making R&D investments decisions. There is a trade-off between risk and pay off in investing in a risky R&D project. A risky R&D project, although less likely to succeed, leads to larger returns if it successful. The decision of a firm to take such risk may be justified by its motive of pre-empting rivals. The idea of trade-off was modelled by Dasgupta and Stiglitz (1980a). However, in their model, only one firm, i.e. a monopolist, makes the decision of investing in R&D. In a different paper (Dasgupta and Stiglitz, 1980b), the authors allowed a number of firms to enter competition, but these firms shared the same R&D function, which means that they were symmetric.

Differently from the previous work, Rosen (1991) modelled the R&D activities of two asymmetric competing firms. The asymmetry is reflected by the difference between the costs of production of the two firms. The large firm has lower cost of production than the small one. Both firms have a menu of R&D projects with different risk levels to choose from. In addition to different R&D projects, they also select the levels of R&D investment. The firms' choices depend on their market position and their levels of technology. In a two stage model setup, both firms choose their R&D investment levels and R&D projects with different levels of risk in the first stage. In the second stage, both firms engage in Cournot competition. Rosen showed that the large firm invests more in R&D, but in safer projects leading to incremental technological innovation. On the contrary, the small firm invests less, but in riskier projects which lead to more radical innovation. Payago-Thotoky (1996) demonstrated that the outcome of Rosen's model was sensitive to the adoption of an additive or multiplicative cost reduction function.[2]

Our simplified model, which will be presented in the next section, is similar to the previous work in the sense that we also incorporate the trade-off of risk and risk-free innovation activities in the model. We differentiate from previous work by arguing that the asymmetry of firms arises not only because of their size or level of productivity,

[1] A review of patent race models is given by Tirole (1988, Chapter 10).
[2] The model setup similar to Rosen's can also be read in Yin and Zuscovitch (1998) and Barros and Nilssen (1999).

but that the asymmetry is also due to industry characteristics and technological opportunities associated with firms.

3. A Simple Model of Non-R&D Innovation Activity

3.1 Model Set-up

We consider two risk-neutral firms that operate in a homogeneous product market. The decision making process of the two firms is modelled as a two-stage non-cooperative game (with no collusion). In the first stage, firms simultaneously engage in two types of cost reduction innovation activities which are purchasing existing technology and conducting R&D (either intramural or extramural R&D).[3] The existing technology is manifested in the form of computer hardware, patents, non-patented inventions, licenses, know-how, trademarks, software, etc. In addition, in order to acquire the available technology to develop product or process innovations, firms organize training for their personnel, implement marketing strategies, and launch technical preparations, all of which involve innovation expenses. In the second stage, both firms participate in a Cournot competition with reduced production cost. Firms choose the level of their innovation budget in the first stage and allocate expenditures to R&D and non-R&D innovation activities. Both firms can obtain complete information of existing technologies which they plan to purchase these. Firms can definitely reduce production cost to a certain degree after purchasing available technologies. In this sense, purchasing existing technologies is a risk-free activity. In contrast, firms may fail in their R&D projects which means that their innovation investments in R&D may go in vain. In conducting R&D, firms thus face a trade-off between the risk of failure and the opportunity of making a technological breakthrough which will bring more dramatic cost reductions than they would obtain by acquiring existing advanced technologies.

In addition to the risk of the innovation projects, firms' decisions are also affected by the technological opportunity in their industry. For firms in a technologically catching-up industry, buying existing technology from industry leaders in other regions or countries may be an optimal choice given the lower risk of doing so. As these firms build up their technological capability and approach the technology frontier, they will be impelled to conduct R&D to move further up the technology ladder, simply because they would not be able to buy more advanced technology than what they already possess. Differently, for firms located in an advanced industry cluster or in a technologically more developed region, there is little room to innovate only by purchasing existing technology, simply because they are already at or close to the technology frontier. Firms' resources and experiences also influence their decisions to invest in R&D. Firms with more financial resources and more experience in R&D would have a higher probability to succeed in their R&D projects. Consequently, they are more likely to invest in such projects.

The marginal costs of production of the two firms are $\hat{c}_i$ (i = 1, 2) before they invest in innovation. In the first stage, the two firms simultaneously determine the size of their innovation expenditures e_i (i = 1, 2). The share of these expenditures on purchasing

[3] Product innovation aiming to improve quality of products can also be considered as cost reduction innovation (Spence, 1984).

existing technology is x_i (i = 1, 2), $0 \leq x_i \leq 1$. Accordingly, the ratio of R&D expenditure to total innovation expenditures is 1- x_i. The share of innovation expenditures for buying existing technology is assumed to be exogenously given. In this way, the share x_i is a parameter in our model. Our goal is to derive the relationship between innovation expenditures e_i and the share of these expenditures spent on existing technology x_i. We will show later how the equilibrium value of e_i changes as the parameter x_i is altered. The cost reduction effect of existing technology is denoted by α, meaning that if the firms spend x_i e_i on purchasing existing technology, they reduce the production cost by α x_i e_i. Here both firms have the same α, which indicates that firms compete in the same pan-European market and are obliged to meet the same quality standards, so they look for existing technologies at the same technological level. The probability of succeeding in R&D projects is β_i (i = 1, 2). The cost reduction effect of successful R&D projects is $\gamma_i(\beta_i)$. If firms invest (1-x_i) e_i in R&D projects and succeed, they reduce the production cost by $\gamma_i(\beta_i)$ (1-x_i) e_i. Different β_i reflect the diverse technological opportunities in the industry and the dissimilar resources and experiences that the two firms possess. α and β_i fall in the set [0, 1]. We assume

(1) $\alpha \neq \gamma_i(\beta_i)$.

A R&D project with a lower probability of success may bring a breakthrough technology which would reduce the production cost more than a less risky project would do. Therefore,

(2) $\gamma_i'(\beta_i) < 0$.

If $\dfrac{\partial(\beta_i \gamma_i(\beta_i))}{\partial \beta_i} = \gamma_i(\beta_i) + \beta_i \gamma_i'(\beta_i)$ >0, then $\dfrac{\dfrac{\gamma_i'(\beta_i)}{\gamma_i(\beta_i)}}{\dfrac{-1}{\beta_i}}$<1, which means that when the probability of success of a R&D project reduces by 1 percent, the effect of cost reduction increases less than 1 percent. Similarly, if $\gamma_i(\beta_i) + \beta_i \gamma_i'(\beta_i)$ <0, then $\dfrac{\dfrac{\gamma_i'(\beta_i)}{\gamma_i(\beta_i)}}{\dfrac{-1}{\beta_i}}$>1, which means that when the probability of success of a R&D project reduces by 1 percent, the effect of cost reduction increases more than 1 percent. Thus the return to the risk of a R&D project is relatively lower under the condition of $\gamma_i(\beta_i) + \beta_i \gamma_i'(\beta_i)$ >0 than it is under the condition of $\gamma_i(\beta_i) + \beta_i \gamma_i'(\beta_i)$ <0.

Both firms' marginal production cost c_i at the end of the first stage is $\hat{c}_i - \alpha x_i e_i - \gamma_i(\beta_i)(1 - x_i) e_i$ if the R&D project is successful. Otherwise, the marginal production cost is $\hat{c}_i - \alpha x_i e_i$. In the second stage of the game, the two firms engage in a Cournot competition in which each firm determines its production quantity q_i (i = 1, 2) conditional to e_i. The inverse demand function is modelled as $p = A - Q$, where $Q = q_1 + q_2$. p denoting the market clearing price. We assume that

(3) $\hat{c}_i < A$.

The model is solved using backward induction. In the second stage, the expected profit of firm i is

(4) $\pi_i = (A-Q)q_i - c_i q_i - e_i$, $i = 1, 2$.[4]

Substituting c_i into the expected profit function yields

(5)
$$\pi_i = \beta\{(A-Q)q_i - [\hat{c}_i - \alpha x_i e_i - \gamma_i(\beta_i)(1-x_i)e_i]q_i - e_i\} + (1-\beta)[(A-Q)q_i - (\hat{c}_i - \alpha x_i e_i)q_i - e_i]$$

$$= (A-Q)q_i - [\hat{c}_i - \alpha x_i e_i - \beta_i \gamma_i(\beta_i)(1-x_i)e_i]q_i - e_i, \quad i = 1, 2.$$

Since α and $\gamma_i(\beta_i)$ represent the cost reduction effect of existing technology and successful R&D projects respectively, the relationship between α and $\gamma_i(\beta_i)$ reveals the firm's characteristics and the technological opportunity of the industry where the firm operates. It follows from equation (5), that when a firm is characterized by the condition that $\alpha - \beta_i \gamma_i(\beta_i) > 0$, purchasing existing technology would be more effective than conducting R&D in terms of cost reduction. In contrast, for a firm characterized by the condition $\alpha - \beta_i \gamma_i(\beta_i) < 0$, conducting R&D would be more effective in terms of reducing production cost.

The Nash-Cournot equilibrium based on equation (5) is computed as

(6) $$\pi_i^* = \frac{\left(A - 2[\hat{c}_i - \alpha x_i e_i - \beta_i \gamma_i(\beta_i)(1-x_i)e_i] + [\hat{c}_j - \alpha x_j e_j - \beta_j \gamma_j(\beta_j)(1-x_j)e_j]\right)^2}{9} - e_i,$$

$i, j = 1, 2, j \neq i$.

Since the firms choose the level of e_i in the first stage, the first order conditions for the profit maximization problem of firm i are

(7) $\dfrac{\partial \pi_i^*}{\partial e_i} = (A - 2\hat{c}_i + \hat{c}_j) + 2s_i e_i - s_j e_j - \dfrac{9}{4s_i} = 0$, where $s_i = \alpha x_i + \beta_i \gamma_i(\beta_i)(1-x_i)$ and $s_j = \alpha x_j + \beta_j \gamma_j(\beta_j)(1-x_j)$, $i, j = 1, 2, j \neq i$.

[4] The fixed cost of production is normalized to zero.

We obtain a sub-game perfect equilibrium value of e_i^* as

(8) $$e_i^* = \frac{3}{2s_i^2} + \frac{3}{4s_i s_j} + \frac{\hat{c}_i - A}{s_i}, \; i, j = 1, 2, j \neq i.$$

In order to have $e_i^*>0$, we need

(9) $$\hat{c}_i > A - \frac{3}{2s_i} - \frac{3}{4s_j}.$$

3.2 Comparative Statics

We unfold our analysis of comparative statics by computing the first order derivative of e_i^* with respect to $\hat{c}_i$, x_i, x_j, α, β_i and β_j as follows:

(10) $$\frac{\partial e_i^*}{\partial \hat{c}_i} = \frac{1}{\alpha x_i + \beta_i \gamma_i(\beta_i)(1 - x_i)},$$

(11) $$\frac{\partial e_i^*}{\partial x_i} = -\left(\frac{3}{s_i^3} + \frac{3}{4s_i^2 s_j} + \frac{\hat{c}_i - A}{s_i^2}\right)(\alpha - \beta_i \gamma_i(\beta_i)),$$

(12) $$\frac{\partial e_i^*}{\partial x_j} = -\frac{3}{4s_i s_j^2}(\alpha - \beta_j \gamma_j(\beta_j)),$$

(13) $$\frac{\partial e_i^*}{\partial \alpha} = -\left[\frac{3x_i}{s_i^3} + \frac{3(x_i s_j + x_j s_i)}{4s_i^2 s_j^2} + \frac{(\hat{c}_i - A)x_i}{s_i^2}\right],$$

(14) $$\frac{\partial e_i^*}{\partial \beta_i} = -(1 - x_i)\left(\frac{3}{s_i^3} + \frac{3}{4s_i^2 s_j} + \frac{\hat{c}_i - A}{s_i^2}\right)(\gamma_i(\beta_i) + \beta_i \gamma_i'(\beta_i)), \text{ and}$$

(15) $$\frac{\partial e_i^*}{\partial \beta_j} = -\frac{3}{4s_i s_j^2}(1 - x_j)(\gamma_j(\beta_j) + \beta_j \gamma_j'(\beta_j))$$

Based on assumption (3) and equation (9),

(16) $\frac{3}{s_i^3}+\frac{3}{4s_i^2s_j}+\frac{\hat{c}_i-A}{s_i^2}$>0 and

(17) $\frac{3x_i}{s_i^3}+\frac{3(x_is_j+x_js_i)}{4s_i^2s_j^2}+\frac{(\hat{c}_i-A)x_i}{s_i^2}$ >0.

Therefore the sign of equation (10) is positive and the sign of equation (13) is negative. The sign of equation (11) depends on the sign of $\alpha-\beta_i\gamma_i(\beta_i)$ and the sign of equation (12) depends on the sign of $\alpha-\beta_j\gamma_j(\beta_j)$. The sign of the equations (14) and (15) are determined by the sign of $\gamma_i(\beta_i)+\beta_i\gamma_i'(\beta_i)$ and of $\gamma_j(\beta_j)+\beta_j\gamma_j'(\beta_j)$, respectively. We establish the following propositions:

Proposition 1: A firm with a relatively higher initial production cost or a lower initial productivity will have higher innovation expenditures.

Proposition 2: A firm will decrease its innovation budget as it invests more in purchasing existing technology if buying existing technology is more effective in terms of cost reductions than conducting R&D ($\alpha-\beta_i\gamma_i(\beta_i)$>0).

A firm will increase its innovation budget as it invests more in purchasing existing technology if buying existing technology is less effective in terms of cost reductions than conducting R&D ($\alpha-\beta_i\gamma_i(\beta_i)$<0).

The explanation for this proposition is straightforward: if acquiring existing technology is more effective for a firm, then the firm will need to invest less in innovation in the future to acquire the same cost reductions to compete in the market. In this sense, choosing the appropriate type of innovation could save resources for firms.

Proposition 3: A firm decreases its innovation expenditures when its competitor increases the share of its innovation budget in purchasing existing technology if for this competitor buying existing technology is more effective in terms of cost reductions than conducting R&D ($\alpha-\beta_j\gamma_j(\beta_j)$>0).

A firm increases its innovation expenditures when its competitor increases the share of its innovation budget in purchasing existing technology if for this competitor buying existing technology is less effective in terms of cost reductions than conducting R&D ($\alpha-\beta_j\gamma_j(\beta_j)$<0).

Proposition 4: A firm decreases its innovation expenditures when the cost reduction effect of purchasing existing technology intensifies.

Proposition 5: If the return to the risk of conducting a R&D project is relatively low ($\gamma_i(\beta_i)+\beta_i\gamma_i'(\beta_i)$ >0), a firm decreases its innovation expenditures as the probability of succeeding in the R&D project increases. If the return to the risk of conducting a R&D project is relatively high ($\gamma_i(\beta_i)+\beta_i\gamma_i'(\beta_i)$ <0), a firm increases its innovation expenditures as the probability of succeeding in the R&D project increases.

This proposition is intuitive in the sense that a firm would increase its investment in a risky R&D project as long as the R&D project renders a high return. On the other hand, it is not worthwhile for a firm increasing its investment in a risky R&D project if the return to risk is low.

Proposition 6: A firm decreases its innovation expenditures as its competitor attains higher probability of succeeding in in-house R&D if the return to the risk of an in-house R&D project is relatively lower for that competitor ($\gamma_j(\beta_j)+\beta_j\gamma_j'(\beta_j)$ >0).

A firm increases its innovation expenditures as it competitor attains higher probability of succeeding in in-house R&D if the return to the risk of an in-house R&D project is relatively higher for that competitor ($\gamma_j(\beta_j)+\beta_j\gamma_j'(\beta_j)$ <0).

4. Empirical Evidence from the Third European Community Innovation Survey

4.1 Data, Dependent and Independent Variables

We explore empirical evidence for the three first propositions using data of the third European Community Innovation Survey (CIS-3). The Community Innovation Survey data are collected on a four-yearly basis. The CIS-1 survey was carried out in 1993, the CIS-2 survey in 1997/1998 and the CIS-3 survey in 2000/2001. As with previous Community Innovation Surveys, CIS-3 is based on the Oslo Manual (second edition from 1997) which provides methodological guidelines and defines the innovation concept. The cleaned dataset includes 14430 manufacturing firms located in 18 European countries, namely Belgium, Germany, Finland, Norway, Island, Italy, Spain, Portugal, Greece, Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Romania, Slovakia and Slovenia.[5] Propositions 4 to 6 are not empirically tested as we cannot construct proper variables using the data covered by CIS-3.

To test the propositions (1) to (3) derived in section 3, we adopt the following general econometric framework:

(18) *(Innovation expenditure intensity) = f {(Key explanatory variable), (control variables)},*

We use the innovation expenditure intensity in 2000, i.e., the ratio of total innovation expenditure to turnover, as the dependent variable. To test proposition 1 which looks into the relationship between innovation expenditures and initial productivity level, the logarithm of labour productivity in 1998 is chosen as the key explanatory variable. For proposition 2, which tests the relationship between innovation expenditures of a firm and its decision to allocate expenditures to R&D and non-R&D innovation activities, we construct the non-R&D innovation expenditure share as a key explanatory variable, which is defined as the ratio of innovation expenditure excluding intramural and extramural R&D expenditure to total innovation expenditure.

An important condition which leads to different theoretical predictions in propositions 2 and 3 is whether buying existing technologies is more effective in terms of cost reductions than conducting R&D. As suggested in Section 3, firms in a technologically catching-up industry or country would consider buying existing technologies from technological leaders as an optimal choice because existing technologies bears less risk. Arguably, a technological leader is most likely to have the highest productivity in an industry or operates in a country where the average productivity of firms is higher than those of the firms in other countries. A firm

[5] The original dataset includes manufacturing and service firms which together amount to 71602 firms. We clean the data through deleting 186 observations with negative values of labour productivity, innovation expenditure intensity, or non-R&D innovation expenditure share. We also delete 180 observations with innovation expenditure intensity greater than 1. We then exclude all service firms which in the cleaned dataset amount to 25999. We also exclude the manufacturing firms which have zero innovation expenditure and that did not report their innovation expenditure (missing value in the dataset), which amount to 17064 and 13756, respectively. Finally we focus on the remaining 14430 manufacturing firms which all have innovation expenditure intensities greater than 0, but less than or equal to 1.

operating in a technologically advanced country is thus more likely to become a technological leader than its counterparts operating in a technologically lagging country. For such a firm, buying existing technologies would be less effective in terms of cost reductions than conducting R&D, simply because it is already at the technological frontier and it thus has to rely on R&D to innovate and further reduce costs.

To identify technologically advanced and lagging countries in Europe, we classify the 18 countries according to the average labour productivity for the NACE two-digit sectors of each country. The average labour productivity of each two-digit manufacturing sector in each country is ranked in Table 1. The arithmetic average of the ranks of all sectors for each country is calculated and then countries are ranked according to this arithmetic average. By ranking the arithmetic average (last row in Table 1) we obtain the relative position of each country. This exercise shows the following ranking of European countries in terms of technological level (in descending order): Italy (the highest level), Belgium, Finland, Norway, Spain, Germany, Iceland, Greece, Slovenia, Portugal, Czech Republic, Latvia, Slovakia, Hungry, Estonia, Lithuania, Romania and Bulgaria (the lowest level). Although this ranking based on labour productivity is by no means perfect, it does demonstrate that the Western European countries (EU-15 countries) have a higher technological level than their counterparts in the East or the new EU member states, which is consistent with the general perception.

Different from proposition 2, proposition 3 illustrates how the investment in non-R&D innovation activities by competitors in the market would affect the level of innovation expenditures of a firm. To test proposition 3, we construct various variables to measure the average ratio of non-R&D innovation expenditure shares of competing firms in the market. Competing firms are grouped according to productivity ranks of the countries. We first divide the 18 European countries into three groups, each with 6 countries. Italy, Belgium, Finland, Norway, Spain and Germany are in the country group with highest labour productivity levels. The competing firms operating in these countries are referred to as Type A firms. Iceland, Greece, Slovenia, Portugal, Czech Republic and Latvia are in the group with medium labour productivity levels. Firms in these six countries are referred to as Type B firms. Slovakia, Hungary, Estonia, Lithuania, Romania and Bulgaria are grouped together as they have lowest labour productivity levels. Competitors operating in these countries are called Type C firms. We construct a variable for the average non-R&D innovation expenditure share of competing firms in the same country group by dividing the sum of non-R&D expenditure of all firms in the same four-digit NACE sector and the same country group except the one under analysis by the sum of total innovation expenditure of all firms in the same four-digit NACE sector and the same country group except the one under analysis. We also compute two variables to measure the average non-R&D innovation expenditure share of competing firms in the different country groups by dividing the sum of non-R&D expenditure of all firms in the same four-digit NACE sector but in the different country group by the sum of total innovation expenditure of all firms in the same four-digit NACE sector but in the different country groups. The methodology of constructing these three variables is shown in Table 2.

To perform a robustness test, we re-divide the 18 countries into two groups, each of them including 9 countries. Italy, Belgium, Finland, Norway, Spain, Germany, Iceland, Greece and Slovenia are regarded as advanced countries with higher labour productivity levels. Portugal, Czech Republic, Latvia, Slovakia, Hungary, Estonia, Lithuania, Romania and Bulgaria are classified as catching-up countries with lower labour productivity levels. Similarly to the analysis based on the three-country-group classification, we compute the average non-R&D innovation expenditure share of competing firms in the same country group and different country group.

Table 1: Ranking of Average Labour Productivity of the European Firms in Each Two-Digit Manufacturing Sector and Each Country

Industry Sector (NACE Code)	BE	BG	CZ	DE	EE	ES	FI	GR	HU	IS	IT	LT	LV	NO	PT	RO	SI	SK
15	1	18	12	6	13	5	4	8	11	9	2	17	15	3	7	16	10	14
16	10	6	2	4	No Data	No Data	No Data	No Data	No Data	5	No Data	11	1	9	3	8	7	No Data
17	1	18	11	3	13	5	4	9	12	8	2	16	15	6	10	17	7	14
18	1	17	11	5	15	3	7	6	10	9	2	14	13	4	8	18	12	16
19	1	17	10	6	12	5	4	7	14	15	No Data	13	3	8	16	9	11	2
20	1	18	14	8	12	7	3	2	15	5	6	16	11	4	9	17	10	13
21	2	17	11	6	14	4	1	12	9	15	No Data	10	3	8	16	7	13	5
22	2	18	12	1	14	5	7	6	10	8	3	17	15	4	11	16	9	13
23	10	4	2	12	1	5	11	No Data	No Data	3	No Data	No Data	8	9	7	6	No Data	No Data
24	1	18	12	7	14	6	4	5	11	8	3	16	15	2	9	17	10	13
25	1	18	12	6	15	5	4	10	9	7	2	13	16	3	8	17	11	14
26	1	18	11	7	14	6	4	8	12	2	5	16	13	3	9	17	10	15
27	2	18	13	6	10	5	1	8	15	7	4	16	12	3	9	17	11	14
28	5	17	12	7	11	6	1	8	13	2	4	15	16	3	10	18	9	14
29	1	17	12	5	13	6	2	10	11	7	3	16	15	4	8	18	9	14
30	9	14	10	5	2	4	7	3	12	No Data	No Data	1	11	15	8	13	6	No Data
31	3	16	12	7	13	6	1	9	15	5	4	17	11	2	8	18	10	14
32	1	17	12	2	14	6	4	8	10	11	No Data	16	3	7	15	9	13	5
33	6	18	13	4	12	7	2	10	11	3	5	15	16	1	8	17	9	14
34	1	17	11	4	13	2	5	14	7	10	No Data	15	6	8	16	9	12	3
35	5	18	13	3	14	4	6	9	10	8	2	12	16	1	11	17	7	15
36	3	17	11	6	15	8	5	7	13	2	1	16	14	4	10	18	9	12
37	6	12	14	3	9	5	1	16	No Data	10	No Data	15	13	2	8	11	7	4
Arithmetic Average	3	16	11	5	12	5	4	8	12	7	3	14	11	5	10	14	10	11

Table 2: Methodology of Constructing the Variables of Average Non-R&D Innovation Expenditure Share of Competing Firms in Different Country Groups (Dividing 18 Countries into Three Groups)

The Variables	The Value of the Variables		
	Regressions on firms in Italy, Belgium, Finland, Norway, Spain and Germany (countries with high labour productivity level)	Regressions on firms in Iceland, Greece, Slovenia, Portugal, Czech Republic and Latvia (countries with medium labour productivity level)	Regressions on firms in Slovakia, Hungary, Estonia, Lithuania, Romania and Bulgaria (countries with low labour productivity level)
Average non-R&D innovation expenditure share of competing firms in the same country group (dividing 18 countries into three groups)	A	B	C
Average non-R&D innovation expenditure share of competing firms in a different country group with the higher labour productivity level	B	A	A
Average non-R&D innovation expenditure share of competing firms in a different country group with the lower labour productivity level	C	C	B

Note: 1. A: Average non-R&D innovation expenditure share of competing firms in Italy, Belgium, Finland, Norway, Spain and Germany (countries with high labour productivity level); B: Average non-R&D innovation expenditure share of competing firms in Iceland, Greece, Slovenia, Portugal, Czech Republic and Latvia (countries with medium labour productivity level); C: Average non-R&D innovation expenditure share of competing firms in Slovakia, Hungary, Estonia, Lithuania, Romania and Bulgaria (countries with low labour productivity level).

4.2 Control Variables

The control variables in the econometric framework include: firm size (measured by the logarithm of number of employees), "innovation independence" variables (independence of product and independence of process innovation), "R&D continuity" variable and country dummy variables.

Schumpeter (1950) was among the first to hypothesize that large firms in a mature capitalist economy generate a disproportionately large share of society's technological advances. Scholars who support this hypothesis have articulated that larger firms possess larger-scale, internally-generated funds, so they secure more resources to conduct risky R&D projects. Scale economies of R&D activities and return to R&D investment due to larger volume of sales also contribute to larger firms' advantages. However, Cohen et al. (1987) argued that these points were flawed because of inadequate attention to the unit of analysis and to industry effects. They found that firm size, overall, has a very small, statistically insignificant effect on business unit R&D intensity. In a recent study, Lee and Sung (2005) contended that firm size does not directly affect R&D intensity, but it does indirectly by affecting firm-specific technological competences.[6] Although no consensus has been reached on the relationship between firm size and R&D or innovation intensity in previous literature, we include the logarithm of the number of employees of a firm as a control variable in our analysis.

Firms which independently develop their product and process innovations may invest more in innovation than those conducting their innovation projects in collaboration with other organizations. We construct variables of independence of product innovation and independence of process innovation to control for the impact of independence of innovation on innovation expenditure intensity. The values of the variables of independence of product or process innovation are 1 if a firm reports that mainly it and its group develop product or process innovations. The values are 0 if a firm reports that it develops product or process innovations in cooperation with other enterprises or institutions or that mainly other enterprises or institutions develop the product or process innovation. Firms which conduct R&D projects continuously and which have a long-term commitment to innovation may spend more on innovation than firms which only occasionally engage in R&D projects. We construct a variable named "continuity of R&D" to control for the effect of continuous R&D on innovation expenditure intensity. The value is 1 if a firm reports that it has engaged in R&D continuously. Otherwise, the value is 0. We are aware that the causal relationship may run from the innovation expenditure intensity to the independence of product and process innovation and to continuity of R&D activity as firms with more resources can afford to develop product and process innovations on their own or continuously finance R&D projects. However, the central focus of this paper is not on the control variables. Consequently we do not instrument the control variables in our analysis.

The firms from each of the 18 countries would on average account for about 5.6 percent of total firms in the sample. However, in our cleaned dataset, German, Italian, Romanian and Spanish firms account for 7.6 percent, 23.8 percent, 8.8 percent and 17.1 percent, respectively, which indicates that firms from these four countries are over-represented. To control for this over-representation, we include four country dummy variables in the regressions. The names of all variables and the methodology of constructing them are listed in Table 3.

[6] The empirical studies on the relationship between firm size and innovation are reviewed by Cohen (1995).

Table 3: The Variables

Variable Name	Definition and Note
Innovation expenditure intensity (dependent variable)	Total innovation expenditure in 2000/ Turnover in 2000
Logarithm of labour productivity (1998) (Unit of labour productivity: 1000 Euro per employee)	Ln(Turnover in 1998 / Employee number in 1998)
Non-R&D innovation expenditure share of the firm under analysis	Innovation expenditure excluding intramural and extramural R&D expenditure / Total innovation expenditure
Average non-R&D innovation expenditure share of competing firms in the different country group with the higher labour productivity level (dividing 18 countries into three groups)	See Table 2
Average non-R&D innovation expenditure share of competing firms in the different country group with the lower labour productivity level (dividing 18 countries into three groups)	See Table 2
Average non-R&D innovation expenditure share of competing firms in the same country group (dividing 18 countries into two groups)	Sum of non-R&D expenditure of all firms in the same four-digit NACE sector and in the same country group except the one under analysis / Sum of total innovation expenditure of all firms in the same four-digit NACE sector and in the same country group except the one under analysis
Average non-R&D innovation expenditure share of competing firms in the different country group (dividing 18 countries into two groups)	Sum of non-R&D expenditure of all firms in the same four-digit NACE sector but in the different country group / Sum of total innovation expenditure of all firms in the same four-digit NACE sector but in the different country group
Firm size	Ln(Employee number in 2000)
Independence of product innovation	The value is 1 if a firm reports that mainly it and its group have developed a product innovation. The value is 0 if a firm reports that it has developed a product innovation in cooperation with other enterprises or institutions, or that mainly other enterprises or institutions have developed the product innovation for the firm
Independence of process innovation	The value is 1 if a firm reports that mainly it and its group have a developed process innovation. The value is 0 if a firm reports that it has developed a process innovation in cooperation with other enterprises or institutions, or mainly other enterprises or institutions have developed the process innovation for the firm
Continuity of R&D	The value is 1 if a firm reports that it has engaged in R&D continuously. Otherwise, the value is 0
Dummy variable for German firms	The value is 1 if a firm is a German firm. Otherwise, the value is 0
Dummy variable for Italian firms	The value is 1 if a firm is an Italian firm. Otherwise, the value is 0
Dummy variable for Romanian firms	The value is 1 if a firm is a Romanian firm. Otherwise, the value is 0
Dummy variable for Spanish firms	The value is 1 if a firm is a Spanish firm. Otherwise, the value is 0

4.3 Econometric Strategy

We only focus on firms which have positive innovation expenditure intensities. We are not interested in firms that did not invest in innovation in the survey period. For those, the key explanatory and the dependent variable are zero when testing for propositions 2 and 3. Given the fact that the values of the dependent variable fall in the range of [0,1], we estimate the regressions using Ordinary Least Square.[7] We control for heteroscedasticity in all regressions.[8]

4.4 Results

To test proposition 1, we regress the dependent variable "innovation expenditure intensity" on the key explanatory variable "logarithm of labour productivity in 1998", controlling for firm size, innovation independence, R&D continuity and the four country dummies. As seen in Table 4, the regression is run for each two-digit sector. For the 23 two-digit sectors, all coefficients of the logarithm of labour productivity in 1998 are negative and 15 of them are statistically significant. The insignificance of some coefficients may be due to the limited number of observations in certain industry sectors, e.g. tobacco products (NACE 16) and petroleum products (NACE 23). In all two-digit sectors, firms with lower productivity in 1998 will have larger innovation expenditure intensities in 2000, although results were only statistically significant in 15 sectors.[9] These results confirm proposition 1.

[7] We could also see the firms with positive innovation expenditures as a selected sample of all firms. Accordingly, we will use a sample selection model such as Heckman's (1979) two-stage estimator in the regression of future analyses.

[8] The variance-covariance matrix is estimated by a sandwich estimator of variance (Huber, 1967). The formula for the robust estimator of variance is $v = \hat{V}(\sum_{j=1}^{N} u_j^{'} u_j)\hat{V}$, where $\hat{V} = (-\frac{\partial^2 \ln L}{\partial \beta^2})^{-1}$, $\ln L = -\frac{n}{2}\ln(2\pi) - \frac{1}{2}\sum_{i=1}^{n}[\ln \sigma_i^2 + \frac{1}{\sigma_i^2}(y - X\beta)'(y - X\beta)]$, and u_j is a row vector, measuring the contribution from the *j*th observation to $\frac{\partial \ln L}{\partial \beta}$. For the linear regression such as the Ordinary Least Square, $v = (X'X)^{-1}(X'\Omega X)(X'X)^{-1}$, which is a White heteroscedasticity consistent estimator (White, 1980).

[9] An interesting result is that we find negative and significant results for 12 out of 15 low- and medium-low tech sectors but only for 3 out of 8 high- and medium-high-tech sectors (cf. footnote 10 for a definition of this classification).

Table 4: Relationship between Innovation Expenditure Intensity (Dependent variable) and Initial Production Cost (Logarithm of Labour Productivity in 1998, Key Explanatory Variable) – Testing proposition 1 - Results

NACE Classification	Industry	Number of Observations	Key Explanatory Variable (Logarithm of Labour Productivity in 1998)
15	Food products and beverages	1583	-.013 (.0032)***
16	Tobacco products	26	-.043 (.025)
17	Textiles	661	-.014 (.0037)***
18	Wearing apparel	485	-.018 (.0034)***
19	Tanning and dressing of leather	252	-.014 (.0078)*
20	Wood and wood products	562	-.012 (.0048)***
21	Pulp and paper	342	-.011 (.010)
22	Publishing and printing	611	-.012 (.0043)***
23	Coke, refined petroleum products	70	-.021 (.029)
24	Chemicals	1100	-.013 (.0036)***
25	Rubber and plastic products	781	-.018 (.0043)***
26	Non-metallic mineral products	793	-.0075 (.0037)**
27	Basic metals	463	-.012 (.0063)*
28	Fabricated metal products	1176	-.017 (.0033)***
29	Machinery and equipment	1549	-.012 (.0029)***
30	Electrical and optical equipment	122	-.011 (.016)
31	Electrical machinery and apparatus	710	-.013 (.0052)**
32	Radio, television and communication equipment	439	-.0017 (.0057)
33	Medical, precision and optical instruments	545	-.0050 (.0064)
34	Motor vehicles	479	-.0075 (.0072)
35	Other transport equipment	324	-.0097 (.0073)
36	Furniture	832	-.014 (.0032)***
37	Recycling	78	-.067 (.024)***

Note: 1. The data in parentheses refer to standard deviations. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.
2. To simplify, the coefficients of the control and dummy variables are not reported.

Manufacturing firms in different sectors do not rely on R&D to acquire technology or to innovate in the same way. In his paper on innovation in British manufacturing industries, Pavitt (1984) concluded that in scale-intensive sectors such as metal manufacturing and vehicles, firms generally tend to develop their own process technology. In textile firms, however, most process innovations come from suppliers. Therefore, R&D intensity does not accurately measure innovation efforts in certain manufacturing sectors, particularly in low-technology sectors (von Tunzelmann and Acha, 2005). In addition to R&D activities, other important contributors to innovation efforts include design, engineering development, testing and prototyping, adoption-related learning activities, and exploration of markets for new products (Smith, 2005). Considering the different extent to which firms rely on non-R&D activities to innovate in different industries, we analyze firms in high- and medium-high-tech sectors and low- and medium-low-tech sectors separately when testing propositions 2 and 3.[10]

Proposition 2 predicts that the innovation expenditure intensity of a firm decreases as its non-R&D innovation expenditure share increases if the firm finds purchasing existing technology more effective in terms of cost reductions than conducting R&D. Firms that compete by buying existing technology normally lag behind the technological frontier. Arguably, they are likely to operate in catching-up countries, instead of advanced ones. Proposition 2 also predicts that the innovation expenditure intensity of a firm increases as its non-R&D innovation expenditure share increases if the firm finds purchasing existing new technology less effective in terms of cost reductions than conducting R&D. Firms that compete by innovating by performing R&D are at the technological frontier. Arguably, they are likely to operate in advanced countries. Our empirical analysis in Table 5 shows that the coefficients of the variable of non-R&D innovation expenditure shares of the firms under analysis are positive and statistically significant in the regressions for firms in the high-labour-productivity and medium-labour-productivity country groups for all sectors, which confirms proposition 2. The theoretical prediction related to firms in the low-labour-productivity country group is not as clear as for the other two country groups (high and medium labour productivity). As a result, it is not surprising to find negative coefficients in the regressions for firms in the low-labour-productivity countries. The coefficient of the variable is negative (-.029) and statistically significant in the regression for the high- and medium-high-tech sectors in the low-labour-productivity country group, which also supports proposition 2. However, the coefficient of the variable in the regression on the low- and medium-low-tech sectors in the low-labour-productivity country group is positive (.030) and statistically significant, which is not consistent with proposition 2. The different signs obtained in the regressions in the high- and medium-high-tech and in the low- and medium-low-tech sectors in countries with low labour productivity levels justify that we estimate for firms in different sectors separately.

Different from proposition 2 which predicts how the decision of a firm in allocating its innovation budget would affect the budget itself, proposition 3 is concerned with how

[10] The high- and medium-high-tech sectors are the industry sectors of NACE 24, 29, 30, 31, 32, 33, 34 and 35. The low- and medium-low-tech sectors are the industry sectors of NACE 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 36 and 37. The classification of high-, medium-high-, medium-low- and low-tech sectors in this paper is fully in line with the standard of Eurostat and the OECD (cf. the Concepts and Definition Database (CODED), Eurostat, available at http://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=LST_NOM&StrGroupCode=CONCEPTS&StrLanguageCode=EN)

the innovation budget of a firm would be affected by competitors' decisions and activities. As shown in Table 5, we use three variables to measure the impact by competing firms. To understand the results of the three variables "average non-R&D innovation expenditure share of competing firms in the same or different country groups, we recall the methodology of constructing the variables described in Table 2.

The results of the variable of "average non-R&D innovation expenditure share of competing firms in the same country group" shows that the decisions of competitors operating in the high-labour-productivity countries (Type A competitors) positively impacts the innovation expenditure intensity of the low- and medium-low-tech sectors in the same country group (the coefficient is .025), thus supporting proposition 3. A negative coefficient (-.021) which is statistically significant at 10 percent is obtained for the competing firms in the medium-labour-productivity countries (Type B competitors) in the regression for the high- and medium-high-tech sectors in the same country group. The negative sign of this variable is not perceived as contradictory evidence to proposition 3, since the theoretical prediction is less clear in terms of whether the sign would be positive or negative for firms in medium-labour-productivity countries.

The results of the variable "average non-R&D innovation expenditure share of competing firms in the different country groups" demonstrate a positive and statistically significant coefficient for Type A competitors which operate in medium-labour-productivity countries in the low and medium-tech sectors (the coefficient is .021). Negative and statistically significant coefficients are attained for Type B competitors (the coefficients are -.028 and -.040) which operate in countries with high labour productivity level in high and medium-high-tech sectors and in countries with low labour productivity level in high and medium-high-tech sectors respectively and Type C (the coefficients are -.023 and -.021) competitors which operate in high-labour-productivity countries in high and medium-high-tech sectors and in medium-labour-productivity countries in low and medium-low-tech sectors respectively. These results are supportive of proposition 3.

Table 5: Relationship between Innovation Expenditure Intensity (Dependent Variable) and Non-R&D Innovation Expenditure Share: Dividing 18 Countries into Three Groups

	Independent variable	Firms in Italy, Belgium, Finland, Norway, Spain and Germany (countries with high labour productivity level)		Firms in Iceland, Greece, Slovenia, Portugal, Czech Republic and Latvia (countries with medium labour productivity level)		Firms in Slovakia, Hungary, Estonia, Lithuania, Romania and Bulgaria (countries with low labour productivity level)	
		High- and medium-high-tech sectors	Low- and medium-low-tech sectors	High- and medium-high-tech sectors	Low- and medium-low-tech sectors	High- and medium-high-tech sectors	Low- and medium-low-tech sectors
Proposition 2	Non-R&D innovation expenditure share of the firm under analysis	.028(.0055)***	.046(.0033)***	.021(.0088)**	.036(.0060)***	-.029(.014)**	.030(.0070)***
Proposition 3	Average non-R&D innovation expenditure share of competing firms in the same country group	-.016(.011)	.025(.0076)*** (Type A competitors)	-.021(.012)* (Type B competitors)	.013(.0097)	-.021(.014)	.015(.0096)
Proposition 3	Average non-R&D innovation expenditure share of competing firms in the different country group with the higher labour productivity level	-.028(.0097)*** (Type B competitors)	.00062(.0058)	-.00032(.018)	.021(.013)* (Type A competitors)	-.019(.019)	-.011(.016)
Proposition 3	Average non-R&D innovation expenditure share of competing firms in the different country group with the lower labour productivity level	-.023(.0063)*** (Type C competitors)	.00012(.0050)	-.011(.0095)	-.021(.011)** (Type C competitors)	-.040(.019)** (Type B competitors)	.0055(.012)
	Firm size	-.0099(.0014)***	-.016(.0012)***	-.0078(.0019)***	-.0074(.0019)***	-.014(.0037)***	-.012(.0020)***
	Independence of product innovation	-.0062(.0039)	-.0063(.0027)**	-.0084(.0063)	-.013(.0049)***	-.029(.0091)***	-.0063(.0049)
	Independence of process innovation	.014(.0038)***	.0097(.0027)***	.016(.0065)**	.022(.0056)***	.0088(.0089)	.015(.0051)***
	Continuity of R&D	.037(.0042)***	.028(.0037)***	.022(.0060)***	.012(.0053)	.00095(.010)	.0048(.0062)
	Dummy variable for German firms	-	.044(.0077)***	-	-	-	-
	Dummy variable for Italian firms	-.033(.0054)***	-.0011(.0035)	-	-	-	-
	Dummy variable of Romanian firms	-	-	-	-	.0046(.011)	-.0061(.0054)
	Dummy variable for Spanish firms	-.030(.0055)***	.0019(.0034)	-	-	-	-
	Number of observations	3130	4457	685	1192	822	2093
	F statistic	F(10, 3119) =15.64***	F(10, 4445)= (cf. Note 2)	F(8, 676)=5.87***	F(8, 1183)=9.31***	F(9, 812)=4.61***	F(9, 2083 =10.58***
	Adjusted R-Squared	.063	.088	.053	.066	.071	.040

Notes: 1. The data in parentheses are standard deviations. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.
2. The F-statistic is not reported by Stata in the result.

Table 6: Relationship between Innovation Expenditure Intensity (Dependent Variable) and Non-R&D Innovation Expenditure Share: Dividing 18 Countries into Two Groups

	Independent variable	Firms in the 9 advanced countries (Italy, Belgium, Finland, Norway, Spain, Germany, Iceland, Greece and Slovenia)		Firms in the 9 catching-up countries (Portugal, Czech Republic, Latvia, Slovakia, Hungary, Estonia, Lithuania, Romania and Bulgaria)	
		High- and medium-high-tech sectors	Low- and medium-low-tech sectors	High- and medium-high-tech sectors	Low- and medium-low-tech sectors
Proposition 2	Non-R&D innovation expenditure share of the firm under analysis	.018(.00)***	.040(.0028)***	-.011(.0096)	.037(.0052)***
Proposition 3	Average non-R&D innovation expenditure share of competing firms in the same country group (dividing 18 countries into two groups)	-.023(.011)** (Competitors operating in advanced countries)	.011(.0060)* (Competitors operating in advanced countries)	-.046(.015)*** (Competitors operating in catching-up countries)	.012(.010)
Proposition 3	Average non-R&D innovation expenditure share of competing firms in the different country group (dividing 18 countries into two groups)	-.025(.0080)*** (Competitors operating in catching-up countries)	.00036(.0050)	-.013(.015)	.0038(.012)
	Firm size (Logarithm of Employee number)	-.0099(.0013)***	-.014(.00097)***	-.014(.0025)***	-.013(.0016)***
	Independence of product innovation	-.0052(.0035)	-.0070(.0024)***	-.021(.0064)***	-.0087(.0040)**
	Independence of process innovation	.015(.0034)***	.012(.0024)***	.0091(.0064)	.014(.0041)***
	Continuity of R&D	.034(.0038)***	.023(.0031)***	.0097(.0071)	.0079(.0047)*
	Dummy variable for German firms	.00048(.0076)	.011(.0044)***	-	-
	Dummy variable for Italian firms	-.019(.0043)***	.0092(.0030)***	-	-
	Dummy variable for Romanian firms	-	-	.0029(.0082)	-.0020(.0044)
	Dummy variable for Spanish firms	-.017(.0045)***	.011(.0029)***	-	-
	Number of observations	3573	5393	1279	2916
	F statistic	F(10,3562)=15.24***	F(10,5382)=52.63***	F(8, 1270)=6.96***	F(8, 2907)=20.40***
	Adjusted R-Squared	.050	.082	.058	.050

Note: 1. The data in parentheses are standard deviations. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.

To test for robustness in propositions 2 and 3, we re-divide the 18 countries into two groups. As for proposition 2, the coefficients (.018 and .040) of the variable of non-R&D innovation expenditure share of the firm under analysis is positive and statistically significant in the regressions on the firms in the advanced countries, for both high and medium-high tech sectors and for low and medium-low-tech sectors, which again confirms proposition 2 (Table 6). However, the coefficient (.037) is also positive in the regression on the firms in the catching-up countries in the low and medium-low tech sectors, which contradicts the theoretical prediction.

As for proposition 3, four coefficients are statistically significant and three are supportive of proposition 3. One coefficient of the four significant ones (-.023) shows that the non-R&D innovation expenditure share of competing firms in advanced countries negatively impacts the innovation expenditure intensity of high- and medium-high-tech sectors' firms in the same country group, which contradicts proposition 3 (Table 6). These results are supportive of proposition 3.

The coefficients of the variable of firm size are universally negative both in Tables 5 and 6, which indicates that larger firms have lower innovation intensities. The degree to which firms independently develop product innovations is negatively associated with their innovation intensity. However, firms which develop process innovations independently and which have continuous R&D activities have higher innovation intensities.

4.5 Discussion for SYSTEMATIC sectors

The universal negative signs of all the coefficients in Table 4 show that for all the SYSTEMATIC sectors firms having lower labour productivity in 1998 would have higher innovation expenditure intensities in 2000. However, the coefficients are only significant for the sectors of food (NACE 15), textiles (NACE 17 and 18), chemicals (NACE 24) and machinery (NACE 29). The insignificant coefficients of some SYSTEMATIC sectors can be attributed to few observations in the regressions of those sectors such as tobacco (NACE 16) (26 observations), energy (NACE 23) (70 observations) and electrical and optical equipment, one of the ICT sub sectors (NACE 30) (122 observations). For radio, television and communication equipment, another ICT sub sector (NACE 32), the coefficient is not significant despite a large number of observations.

It is very difficult to disentangle the SYSTEMATIC sectors from the results testing propositions 2 and 3. The high- and medium-high-tech sectors in Tables 5 and 6 include the industry sectors of NACE 24 and 29 to 35. SYSTEMATIC sectors, including chemicals (NACE 24), machinery (NACE 29), ICT (NACE 30 and 32), automotive (NACE 34) and aerospace (NACE 35.3), account for a majority part of the high-and medium-high-tech sectors. Therefore, we argue that the results related to the high- and medium-high-tech sectors are applicable to SYSTEMATIC sectors of NACE 24, 29, 30, 32, 34 and 35.3. However, the weight of the SYSTEMATIC sectors, including food (NACE 15 and 16), textiles (NACE 17 and 18) and energy (NACE 23) is much less significant in the low- and medium-low-tech sectors examined in Tables 5 and 6, which include NACE 15 to 23, 25 to 28, 36 and 37.

5. Summary and Policy Conclusions

In this paper, we develop a two-stage non-cooperative game to model the decision of firms with regard to the size of their innovation expenditures and the allocation of these expenditures between R&D and non-R&D innovation activities. We demonstrate how the initial production cost or productivity of a firm, the cost reduction effect of existing technology and performing R&D, and the share of non-R&D innovation expenditures of a firm and its competitors would affect the size of the innovation expenditures of a firm.

Following the theoretical framework and arguments, we examine the data of the third European Community Innovation Survey (CIS-3) to provide empirical evidence. We find that in all two-digit NACE sectors, European manufacturing firms with lower labour productivity in 1998 have larger innovation expenditure intensities in 2000, which conforms to the theoretical proposition that a firm with lower initial productivity will have a larger innovation budget. This results would suggest a catching-up process in innovation spending as firms which start at lower levels of productivity spend relatively more on innovation than firms which start at higher level of productivity. Similarly, there will be a catching-up process within the same industry between different countries if there are differences in labour productivity levels between these countries. However, we do need to recall that our econometric analysis is focusing on development over a period of three years whereas catching-up processes normally take more time. The predicted catching-up process in our model might thus not yet be visible in the observed productivity developments within Europe.

By regressing the innovation expenditure intensity of European manufacturing firms on their non-R&D innovation expenditure shares, we demonstrate evidence that supports the proposition that a firm which is away from the technological frontier should increase its innovation expenditures on acquiring existing technologies so it can maintain its competitive edge with a smaller innovation budget. Similarly, a firm which is at the technological frontier and which spends less on R&D would have to increase its innovation expenditures to be able to compete in its market. In general, these propositions lead to the argument that choosing appropriate ways of innovation can save resources for firms. While for firms away from the technological frontier would be more economical to acquire existing technologies, for firms already at the frontier, it would be better to continue to push it forward.

To test the theoretical proposition about how the innovation expenditures of a firm would be affected by the decision of its competitors with regard to the allocation of their innovation expenditures, we explore the relationship between the innovation expenditure intensity of a firm and the non-R&D innovation shares of its competitors. The results obtained in the empirical analysis are by and large consistent with the theoretical predictions of our model. In other words, a firm will decrease its innovation expenditures when its competitor increases the share of its innovation budget in purchasing existing technology if for this competitor buying existing technology is more effective in terms of cost reductions than conducting R&D.

One conclusion is that policies aimed at increasing innovation co-operation between firms, universities and research institutes will close the gap to the technological frontier and thereby raise the share of R&D-based innovation. An improvement of existing R&D support mechanisms will further stimulate firms to invest in R&D. However, as shown by Arundel et al. (2008), non-R&D innovators develop in-house innovative capabilities as non-R&D innovative activities, also requiring creative efforts leading to productivity improvements, improved competitiveness and to new and improved products and processes. It therefore seems more justified to pursue policies aimed at improving the use of existing technologies by technology adoption, incremental changes, imitation and combining existing knowledge in new ways for firms not as technologically advanced as so-called innovation or technology leaders. This will in particular apply for firms in more low-tech industries and in lagging countries. But R&D policies are needed for those firms close to or even at the technological frontier, so as to ensure that this frontier will be continuously pushed ahead, increasing the stock of available technologies and innovations, which not only benefit these high-technology firms, but also the firms who rely for their innovation on adopting and implementing existing technologies through non-R&D innovation.

For firms it is important to carefully review different innovation strategies, whether to follow an R&D innovation strategy by investing in R&D or to follow a non-R&D by adopting and acquiring existing technologies. For firms far from the technological frontier the latter strategy is more efficient and more cost effective. Choosing the right strategy will not only save scarce resources, but will also make their innovation investments more effective. Firms should also actively be involved in formal and informal networks to increase their access to available knowledge which will facilitate their decision to invest in the appropriate innovation strategy.

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